575953

Abstract Submitted to the 7^{th} Asian Congress of Fluid Mechanics
Dec. 8-12, 1997, Madras, India

THE EFFECT OF TRANSITION MODELING ON THE PREDICTION OF COMPRESSIBLE DEEP DYNAMIC STALL

W.Geissler*,† M.S.Chandrasekhara*,‡ M.F.Platzer*, L.W.Carr**

*Department of Aeronautics and Astronautics
Naval Postgraduate School, Monterey, CA 93943, U.S.A.
**U.S.Army ATCOM, AvRDEC and Fluid Mechanics Lab. Branch
NASA Ames Research Center, Moffett Field, CA 94035, U.S.A.

ABSTRACT The importance of transition modeling in the computation of compressible, unsteady separated flows is discussed. The study showed that it is critical to predict the experimentally attained transition point properly in order to obtain good agreement with data at the same Mach number and Reynolds number.

1. Introduction

Recent advances in computing power have made it possible to obtain solutions of the 2- and 3-dimensional Navier-Stokes equations for complex separated flow problems, such as dynamic stall on airfoils and finite-span wings. Calculations by Clarkson et al[1] have shown that simple algebraic and half-equation turbulence models are inadequate to predict the measured dynamic stall hysteresis loops. It is well recognized that leading-edge stall is preceded by the development of a leading-edge separation bubble for chord-based Reynolds number $\leq 1 \times 10^6$. The size of the bubble is determined by the transition and entrainment processes within the bubble. Two key parameters, namely the transition onset location and the transition length need to be modeled correctly for successful prediction of the bubble and its bursting, as shown in Refs. [2]-[4]. Compressible dynamic stall studies by Ekaterinaris and Platzer[5] at $Re = 4 \times 10^6$ showed that transition plays a dominant role even at full-scale Reynolds numbers since it is a leading-edge type of stall and hence, the physics of transition needs to be incorporated in modeling the flow.

In the present paper, the deep dynamic stall flow over a NACA 0012 airfoil is studied at $Re = 1.1 \times 10^6$, where corresponding experimental data are available[6]. However, the transition modeling used in Ref. 5 for high Reynolds numbers is replaced by that used by Ekaterinaris et al[2] for transitional Reynolds number flows. The methodology is based on use of Michel's criterion for determination of the transition onset location, (given by the matching of the two functions $Re_\theta(x)$ and $f(x) = 1.174(1.0 + 22400)/Re_x^{0.46}$), with Re_x and Re_θ based on u_∞ rather than the boundary layer edge velocity u_e. The transition length is obtained using the Chen-Thyson model:

$$\gamma_{tr}(x) = 1 - exp\Big[\Big(- \frac{u_e^3}{G_{\gamma_{tr}}\nu^2}\Big) Re_{x_{tr}}^{-1.34}(x - x_{tr}) \int_{x_{tr}}^{x} \frac{dx}{u_e}\Big]$$

with $\quad G_{\gamma_{tr}} = 213[log(Re_{x_{tr}}) - 4.7323]/3 \quad$ as the transition constant.

---

† *On leave from DLR, Göttingen, Germany*

‡ Corresponding Author, *Mailing Address: M.S. 260-1, NASA Ames Research Center, Moffett Field, CA 94035-1000, U.S.A.*

2. Experimental Investigations of Transition Effects on Dynamic Stall

In [6], the Reynolds number effects on oscillating airfoil compressible dynamic stall flow have been investigated on two NACA 0012 airfoil models at constant Mach Numbers, with and without tripping the boundary layer on both models. The corresponding (untripped) values of Re_c were 0.54×10^6 and 1.1×10^6 respectively. The experiments showed that with increasing Reynolds number, the length of the laminar separation bubble was reduced. Further, dynamic stall onset was shifted to higher incidences during the upstroke of the airfoil and the flow was able to withstand higher adverse pressure gradients. In the present study different transition onset models are applied to simulate the experimental conditions, i.e. natural transition and boundary layer tripping.

3. Implementation of Transition Model into Navier-Stokes Code

The present numerical study uses a time-accurate (Beam and Warming) 2D Navier-Stokes code[7]. Calculations until now used fully turbulent flow during the entire oscillation cycle. As shown in [6], since transition plays a dominant role in the initiation and further development of the dynamic stall process, it has to be taken into account in numerical modeling as well. It is even more important to account for transition if research towards favorably influencing dynamic stall (or other aerodynamic properties) is pursued by means of dynamic airfoil shape modifications. Recent numerical studies by Geissler and Raffel[8] and Geissler and Sobieczky[9] as well as wind tunnel measurements by Chandrasekhara et al[10] have already shown the considerable benefits of such an approach.

In the present numerical study, different measures to determine transition onset have been investigated on a NACA 0012 airfoil section in oscillatory pitching motion. To match experimental data in [6] the following set of parameters have been used in the study: incidence,$\alpha = 10^o + 10^o \sin\omega t$; Mach number, M = 0.3; Reynolds number,$Re = 1.1 \times 10^6$; reduced frequency,$k = \frac{\pi f c}{u_\infty} = 0.05$. For the determination of transition onset, three different options have been used: (a) prescribed transition-onset corresponding to the tripping device in the experiment; (b) calculation of transition onset by Michel's criterion; (c) calculation of transition onset at the instantaneous position of the pressure minimum.

4. Results and Discussion

Figure 1 shows a typical result of the present investigation. The pressure minimum is plotted versus incidence during the airfoil upstroke. The solid curve is obtained if fully turbulent flow is assumed. Dynamic stall onset is characterized by the rapid development of the dynamic stall vortex which occurs approximately at the maximum of this curve.

The dotted curve is obtained by prescribing the transition onset at x/c = 0.015 to match the leading edge of the transition strip (located between x/c = 0.015 and 0.030) in the experiments[6]. Remarkable agreement of this (dotted) curve with the experimental (tripped) data can be observed. Changing transition onset upstream of x/c = 0.015 to x/c=0.005, (not shown) shifts the maximum of the curve towards the fully turbulent limit. Shifting transition onset downstream towards the end of the transition strip at x/c = 0.03 leads to an earlier dynamic stall onset (at α = 12 deg) and shows a trend towards numerical instability.

The dashed curve in Fig.1 indicates the result obtained with Michel's criterion (assumed to approximately determine natural transition onset), which has been proven to be applicable for $Re \geq 1 \times 10^6$. Also shown in the plot is the experimental result for free (untripped) transition. The maximum of the experimental curve is obtained prior to the maximum obtained with Michel's criterion. In both experimental and numerical cases a trend to shift dynamic stall onset slightly beyond the point obtained with tripping can be observed.

The long-dashed curve in Fig. 1 finally indicates the case of transition onset fixed to the instantaneous position of the pressure minimum, which is located very close to the airfoil leading edge. This results in a delay of dynamic stall onset towards the fully turbulent case.

Figure 2 compares the calculated positions of transition onset as obtained by Michel's criterion (dashed curve) and from the $C_{p_{min}}$ locations (solid curve). Also shown are the fixed positions of transition onset which have been used in the present calculations. The pressure minimum moves rapidly upstream from about 14% chord at $\alpha = 0$ deg. to $x/c \approx 0.005$ for $\alpha = 10$ deg. Michel's criterion predicts transition onset further downstream and reaches the 0.5% location beyond $\alpha = 15$ deg. Indicated in the plot are also the (constant) positions of fixed transition onset. The distance between these lines and the pressure minimum indicates the area where the laminar boundary layer is subjected to an adverse pressure gradient.

Figure 3 shows the calculated force and moment coefficient loops for the cycle. Two different cases are illustrated: the fully turbulent flow (solid curves - the reference case) and the case of transition onset fixed at x/c = 0.015. A considerable reduction of maximum lift can be observed in the transitional case. Dynamic stall onset occurs about 4-5 deg earlier within the oscillatory loop when transition modeling is included. Similarly, the drag-rise and the beginning of moment stall occur earlier in the cycle.

5. Conclusions and Future Investigations

With the implementation of a transition model into the time-accurate Navier-Stokes code the critical role of transition on dynamic stall onset has been documented. The rather simple Chen-Thyson model which has been used in a quasi-steady manner gives results comparing reasonably with the experimental data. The study has also addressed the problem of determination of the transition onset location. If tripping is used in the experiment, best agreement with numerical calculations is obtained by fixing the transition onset point at leading edge of the transition strip. Michel's criterion gives transition onset locations which seem to be too far downstream. Nevertheless, the results of the present study show trends similar to those seen in experiments. Use of suction peak location for transition onset pushes dynamic stall onset towards the fully turbulent limit. The present results provide useful design guidance for the modification of the airfoil shape to delay dynamic stall onset.

References

[1] Clarkson,J.D., Ekaterinaris,J.A., Platzer,M.F., Proc. Symp. Unsteady Aero. Aeroacoustics and Aeroelasticity of Turbomachines and Propellers, Ed. Atassi, H.M., Springer Verlag 1991, pp. 415-432.

[2] Ekaterinaris,J.A., Chandrasekhara,M.S., Platzer,M.F., J. Aircraft, 32, 3, pp. 625-630.

[3] Van Dyken,R.D., Ekaterinaris,J.A., Chandrasekhara,M.S., Platzer,M.F., AIAA J., 34, 7, pp. 1420-1427.

[4] Sanz,W., Platzer,M.F., ASME Paper 96-GT-487, Jun. 1996.

[5] Ekaterinaris,J.A., Platzer,M.F., J. Turbomachinery, 118, Apr. 1996, pp.118-203.

[6] Chandrasekhara,M.S., Wilder,M.C., Carr,L.W., AIAA Paper 96-0073, Jan. 1996.

[7] Geissler,W., Vollmers,H., Proc. of the 18^{th} European Rotorcraft Forum, Sep. 15-18, 1992, Avignon, France.

[8] Geissler,W., Raffel,M., Proc. of the 19^{th} European Rotorcraft Forum, Paper C2, Sep. 14-16, 1993, Como, Italy.

[9] Geissler,W., Sobieczky,H., AGARD-CP-552.

[10] Chandrasekhara,M.S., Wilder,M.C., Carr,L.W., AIAA Paper 97-0655, Jan. 1997.